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No. 127. December, 1929. Vol. XXII.

On a partially fused quartz-felspar-rock and on glomero-granular texture.

(With Plate VII.)

By Leonard Hawkes, D.Sc., F.G.S.
Reader in Geology, Bedford College, London University.

[Read June 11, 1929.]

The Partially Fused Granite.

THE specimen to be described was found in 1925 by Miss H. K. Cargill and Miss J. A. Ledeboer on a scree slope beneath a gully in the basaltic capping of the Slaufrudal granite-granophyre stock at Kvosafoss, SE. Iceland.[1] Unfortunately the rock was not discovered in situ, but it must belong to the upper part of the stock or a dike apophysis of it. An examination of the rock was begun by Miss Ledeboer, but she was unable to continue the work; I am indebted to her for the photographs of pl. VII, figs. 1 and 2.

The specimen is dark grey with evenly scattered, irregularly shaped blebs of light-coloured felspar (pl. VII, fig. 1). In thin section larger crystals of quartz and felspar are seen in a microcrystalline groundmass of the same minerals: zircon, magnetite, and chlorite pseudomorphs are estimated to comprise one per cent. The felspar is mainly perthite with rare acid oligoclase; the average diameter of the felspars (1 to 2 mm.) is slightly greater than that of the quartzes. The felspars occur in aggregates of intergrown anhedral crystals, as

[1] H. K. Cargill, L. Hawkes, and J. A. Ledeboer, Quart. Journ. Geol. Soc. London, 1928, vol. 84, pp. 505–539.

do the quartzes. The aggregates are composed either of felspars or of quartz, in no case are felspar and quartz phenocrysts in growth contact, although very rarely the two touch in a manner which suggests that displacement has taken place. These aggregates have smoothly curved sinuous outlines, and there is commonly a close parallelism of the borders of neighbouring quartz and felspar areas, which are separated by ramifying lanes of groundmass averaging $\frac{1}{2}$ mm. in width. The structure is illustrated in fig. 1 and the photomicrographs of plate VII. Corrosion of both quartz and felspar is shown, being especially marked in the felspar. Where the aggregates are close together the corrosion outlines are smoothly curving, but where more groundmass intervenes the felspar exhibits fretted borders (pl. VII, fig. 4).

The groundmass shows a tendency to spherulitic structure and graphic intergrowths may be detected in it. Its larger quartz grains are 0·12 mm. across; they may adjoin the quartz phenocrysts, in which case they are in optical continuity with them. There is a tendency for the quartz and felspar to segregate at the borders of their respective phenocrysts, but the quartz may be concentrated in the middle of the lanes (pl. VII, fig. 4). Opaque material is scattered through the groundmass as fine dots and acicular forms (average length 0·02 mm.) and commonly marks the borders of the felspar areas (pl. VII, figs. 3 and 4).

The volume composition was found with the Shand recording micrometer. Considerable variations were given by eight sections: quartz 12·8–25·7, felspar 21·6–41·4, groundmass 41·7–52·7 %, the mean result being:

Phenocrysts	Quartz . . .	18·2 %
	Felspar . . .	35·4
Groundmass		46·4.

The origin of the structure is best studied from a consideration of the groundmass. This cannot represent a later impregnation of a granitic rock, for the borders of the aggregates, although parallel, do not fit one another, and it would be difficult to explain why an invading liquid had never failed to penetrate any quartz-felspar contact.

The texture of the groundmass is identical with that of many quartz-porphyries. These latter rocks of dominant quartz-felspar composition have originated either (*a*) by intrusion and rapid cooling

of a magma holding phenocrysts, or (*b*) by sudden increase in viscosity of a partially crystallized magma under conditions of steady cooling. With regard to (*a*), as considerable corrosion of phenocrysts has taken place, the amount of liquid must have been less than 46·4 %, and the intrusion of such a crystal mixture would have been attended

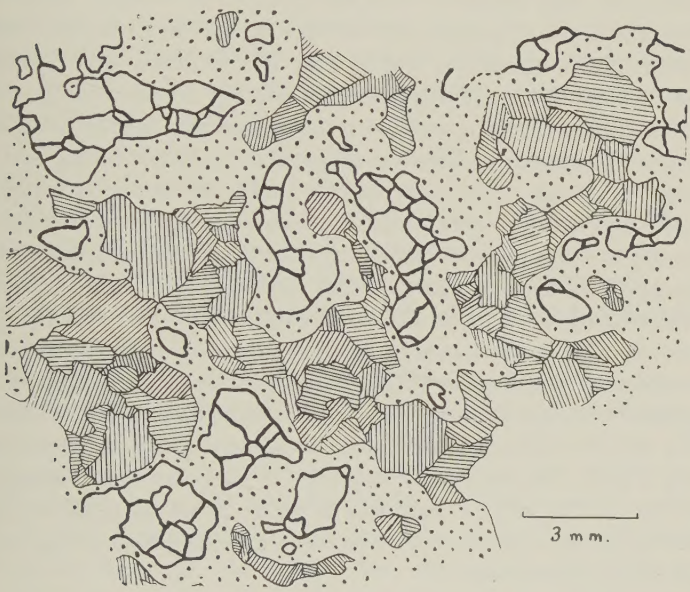


FIG. 1. Drawing from a thin section of the Kvosafoss porphyry. Felspars lined, quartzes clear, groundmass stippled.

by disturbance of the crystalline portion, whereas although slight displacement of some phenocrystal areas has occurred, there is no sign of fracture even in those with marked elongation (pl. VII, fig. 2). A consideration of (*b*) provides no clue to the abnormal corrosion that has obtained, for although the quartz of porphyries is commonly corroded, the felspar never shows such marked effects as in this rock.

The narrowness of the groundmass veins—especially in relation to the size of the phenocrysts—and the close parallelism of their borders, indicate that the phenocrystal areas were originally in contact, i.e. that the rock was holocrystalline and coarse-grained, and has suffered partial fusion with the crystallization of the melt to a finer grain. The monomineralic composition of the coarse-grained areas is significant. Fusion has been restricted to the quartz-felspar

contacts, neither quartz nor felspar show signs of melting. The phenomenon is clearly one of corrosion.

That fusion may take place at the contacts of different solids if the temperature rises above the eutectic point, though not to the melting point of the most easily fusible constituent, was established by Hallock,[1] who prepared a liquid globule of Wood's metal by heating the requisite proportions of 'fine filings' of cadmium (melting point 320°), tin (m. p. 232°), lead (m. p. 326°), and bismuth (m. p. 269°) at 100°. Hallock also found that when a piece of tin was placed on a carefully cleaned piece of lead and heated in an air-bath to 190° melting occurred at the contact in a few hours, and he formulated the law: 'An alloy can be produced out of its original constituents without considerable pressure if the temperature be above the melting point of the alloy, even though it be far below the melting point of the most easily fusible constituent.' This conclusion is confirmed by the work of Benedicks and Arpi.[2] The principle has proved of value in the hands of the investigators at the Geophysical Laboratory in Washington in the determination of the equilibrium diagrams of silicate mixtures, in which undercooling so easily obtains that it may be impossible to find the true temperature of crystallization of a melt. Superheating, however, is rare, and many examples could be cited of silicate mixtures in which it has been shown that fusion begins at a temperature below the melting point of the most easily fusible constituent.

In the Icelandic rock the quartz shows no sign of inversion to tridymite or cristobalite. Under atmospheric pressure this would indicate that the temperature has not exceeded 870° for longer than a few days at any rate.[3] The inversion-point is raised with increased pressure by an amount which has been calculated at 100° for a depth of $2\frac{1}{2}$ miles in the crust,[4] which depth would be a liberal estimate for the original thickness of the cover of the rock. We may thus consider 970° as an upper limit for the temperature to which the rock has been raised. The orthoclase-albite-silica eutectic temperature is not known. Vogt suggests 975° for the albite-silica and orthoclase-silica eutectics,[5] and that of the ternary eutectic point would be lower

[1] W. Hallock, Bull. U.S. Geol. Survey, 1890, no. 60, pp. 147–148.

[2] C. Benedicks and R. Arpi, Revue de Métallurgie, 1907, vol. 4, p. 416.

[3] R. B. Sosman, The properties of silica, 1927, p. 783.

[4] N. L. Bowen in E. E. Fairbanks, The laboratory investigation of ores, 1928, p. 181.

[5] J. H. L. Vogt, Journ. Geol. Chicago, 1921, vol. 29, p. 336.

than this, showing that there is no reason to doubt the possibility of the fusion of the rock in the dry state within the range of the stability of the quartz.

Dr. J. A. Smythe of Armstrong College, Newcastle-upon-Tyne, has conducted some experiments to ascertain whether the operation of Hallock's law could be demonstrated with quartz and felspar. Specimens of granite and granophyre from the Slaufrudal stock, composed largely of quartz and perthite with rare acid oligoclase, were heated under the conditions described below and examined afterwards in thin section:

1,000° for 3 hours: no change.

1,020° for 2½ hours: no change.

1,050° for 6 hours, with a possible rise to 1,100° during the last hour: almost complete fusion of the perthite only.

1,060°–1,070° for 5 hours; partial fusion of perthite only.

1,170° for 4 hours: perthite fused, oligoclase showing partial fusion.

Smoothed pieces of quartz and orthoclase bound together with platinum wire were heated for 6 hours at 1,050° with no change, and for 4 hours at 1,200°–1,230° with partial fusion of the felspar. Cones were made of mixtures of finely ground quartz and felspar in the eutectic proportion and heated at 1,050° for 6 hours with no change. In all these experiments no sign could be detected of any corrosion of quartz, although the temperature was well above that of the eutectic. We may conclude that the action is too sluggish to give results under the comparatively short duration of the experiments, whereas fusion may well occur under the prolonged influence of contact-metamorphism assisted by the intimate granular contact which must obtain under the pressures existing in the earth's crust. One cannot rule out the possibility that the fusion of the rock was assisted by the presence of water, although in that case signs of solution might have been expected at the contacts of grains of the same mineral-species.

It has commonly been assumed that the acid rocks require higher temperatures for fusion than the basic, but if we accept dry fusion for the Kvosafoss rock we must conclude that granites of quartz-orthoclase-albite eutectic composition will fuse completely at a temperature not higher than 970°. In this connexion we note that Bowen in combating the idea that dry granite melts at a higher temperature than dry basalt, writes: 'It has been demonstrated

experimentally in the dry way by Shepherd and by Greig that granite is converted into glass at a temperature well below that at which basalt begins to show any change'.[1]

If the suggested explanation is correct, the groundmass, being derived from the solution of quartz and felspar in one another, must be of eutectic composition. From the data given of the composition of the Icelandic graphic granites[2] the eutectic volume ratio quartz/felspar may be taken as 0·4, which applied to the groundmass gives the composition:

	Quartz.	Felspar.
Phenocrysts	18·2	35·4
Groundmass	13·2	33·2
	31·4 %	68·6 %

This gives a quartz/felspar ratio for the original rock of 0·46, the ratios for the granitic types of the stock varying from 0·49 to 0·56. Having regard to the considerable proportion of groundmass and the uncertainty of the exact eutectic ratio, the agreement of the deduced composition to that of the granitic types may be considered satisfactory.

Dr. H. H. Thomas has drawn my attention to the resemblance of the structure of the Kvosafoss rock to that of a Mull gneiss (Geol. Survey Coll., no. 18,025) which has suffered partial fusion from a dolerite intrusion.[3] There is a similar parallelism of monomineralic areas of quartz and felspar separated by glass, only in this case the temperature must have been higher, as the felspar shows incipient melting phenomena.

I am indebted to Dr. Smythe for his experimental work and also for helpful criticism during the consideration of this problem.

Glomero-granular Texture.

Whatever explanation be adopted of the origin of the Kvosafoss porphyry, one characteristic of the crystallization history is evidenced in the coarse-grained part of the rock, viz. that in some areas quartzes only have grown, in others felspars only. The disposition of the groundmass between these areas at once draws attention to this

[1] N. L. Bowen, The evolution of the igneous rocks, 1928, p. 298.

[2] H. K. Cargill, L. Hawkes, and J. A. Ledeboer, 1928, loc. cit., p. 529.

[3] Mem. Geol. Survey Scotland, 1911, no. 35, The geology of Oronsay with part of the Ross of Mull.

feature, which had not been noted in the previous study of the granite types of the Slaufrudal stock; but a re-examination of them revealed that there is a distinct tendency to aggregation of this kind, giving rise to monomineralic clusters of several individuals in anhedral intergrowth. Many sections of different granites were examined, and this texture—for which the name 'glomero-granular' is suggested when occurring in non-foliated rocks—was found to be common in

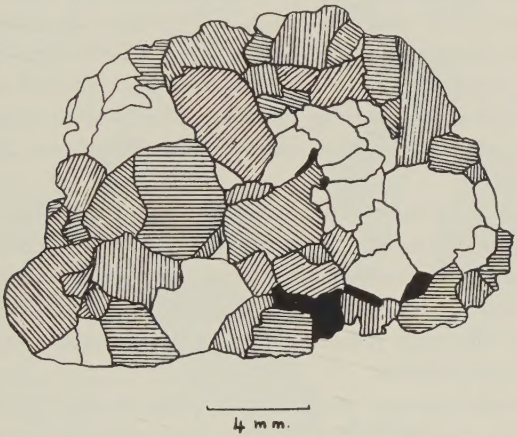


Fig. 2. Alkali-granite, Quincy, Mass., U.S.A. Felspar lined, quartz clear, iron-ore and ferromagnesian constituents black.

the coarser grained types. An illustration of this is given from a thin section of the Quincy granite (fig. 2).

The texture is well developed in the west of England granites, of which Teall writes: 'Quartz generally occurs in the form of grains and granular aggregates'.[1] It is well known that dynamic metamorphism may result in the breaking up of larger crystals into smaller ones, even if it has been insufficient to produce foliation, and this is probably in part the explanation of the texture of the Quincy granite, as the quartz gives undulose extinction; and Dale writes of this rock, 'this [mechanical] strain has been carried far enough to granulate the quartz'.[2] The glomero-granular texture is, however, also found in rocks which show no sign of having been subjected to strain, and in these the texture must be original, a conclusion which may be supported from a study of the normal quartz-porphyries.

[1] J. J. H. Teall, British Petrography, 1888, p. 314.
[2] T. N. Dale, Bull. U.S. Geol. Survey, 1908, no. 354, p. 56.

The monomineralic glomero-porphyritic clusters of quartz-felspar-porphyries appear to represent an early stage in the production of the glomero-granular texture. An examination of a large number of sections of these rocks bearing large phenocrysts showed that whereas the felspar, and more rarely the quartz, commonly occur in groups of two and three or more intergrown individuals, it is rare to find quartz and felspar in contact, excluding those rare cases of felspar phenocrysts which enclose quartz in graphic intergrowth. Also the phenocrysts of one kind may exhibit a segregation in small areas, an arrangement which is illustrated from the Armboth dike (fig. 3). The continuous growth of quartz and felspar in the delimited areas would result in the glomero-granular texture. Should these phenocrysts be intratelluric, their segregation, despite flow disturbance, is none the less significant.

The causation of the texture, when it cannot be related to granulation of larger individuals, is obscure. One would expect the centres of crystallization of the first constituent to form to be evenly spaced, and when, as in the porphyries and granites, the two main constituents crystallize at the same time the phenomenon of their segregation is all the more remarkable.

In 'synneusis' texture small early-formed crystals of one or more species 'swim together', but there is no evidence that the larger individuals do so, and their monomineralic attachments render such an explanation improbable. The coarse anhedral texture of the groups indicates that there has been a definite clustering of the centres of crystallization. Liquid immiscibility cannot be invoked in explanation of the phenomena. No concentration of quartz and felspar is to be detected in separate areas of the groundmass of the porphyries; and furthermore, in the crystallization of an association of two immiscible liquids, the first solid phase to appear in each liquid is one and the same component.[1] Thus for immiscible liquids giving quartz and felspar, crystallization of one constituent—say felspar—will begin in one liquid and continue until that liquid is used up, when felspar will grow in the remaining liquid until the eutectic point is reached with final crystallization of quartz and felspar together. The product will be composed of clusters of felspar crystals and a quartz-felspar aggregate: the separation of the two constituents now under consideration will not obtain. Application of the phase rule shows that it is impossible for the two components of a binary

[1] See N. L. Bowen, 1928, loc. cit., pp. 8–10.

system, or the three of the ternary one, to crystallize simultaneously in an association of two liquids, and this excludes any application of immiscibility to the present case. The structure would result if the original centres of crystallization were far apart and the growing crystals in some way initiated new centres near to them, but this

Fig. 3. Quartz-porphyry, Armboth dike, Thirlmere, Cumberland Felspar lined, quartz outlined, groundmass remainder. The broken lines delimit the areas of quartz and felspar phenocrysts.

would be difficult to understand, unless with movement in the magma the crystals set up new centres in their wake.

The glomero-granular and the graphic are contrasted textures: in the former the tendency is for contact of different species to be avoided until the later stages of solidification; in the latter there is intimate association from the first. The conditions which it has been suggested favour the granular rather than the graphic texture are slow rate of cooling and abundance of mineralizers.[1] The presence of the glomero-granular disposition in the coarser granular types harmonizes with this view, but the occurrence of graphic intergrowth phenocrysts in some porphyries presents a difficulty, unless such

[1] H. K. Cargill, L. Hawkes, and J. Ledeboer, 1928, loc. cit., p. 528.

phenocrysts grew at an earlier stage in a larger body of magma poorer in mineralizers.

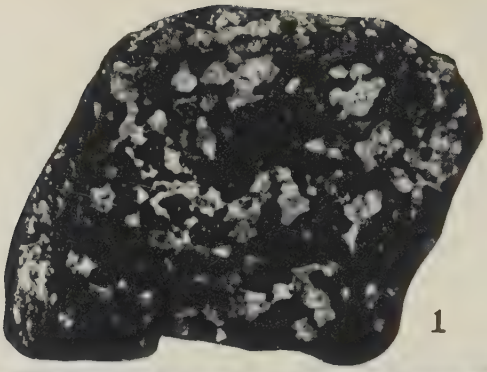
Whatever the cause, it is clear that in the normal undisturbed crystallization of a granite magma under conditions giving rise to coarse grain there is a tendency for aggregation of minerals of the same kind. This phenomenon has not been studied in other rocks, but its recognition calls for caution in adopting for all occurrences of monomineralic nodules explanations which are based upon accidental or abnormal circumstances, such as liquid immiscibility, the breaking up of monomineralic rock, and the accumulation of crystals in restricted parts of channels.

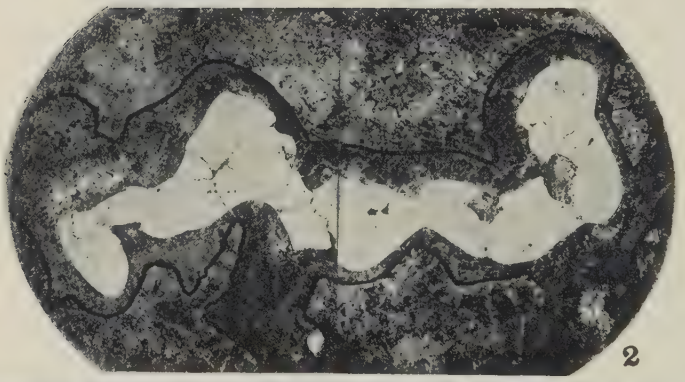
It is important to distinguish between glomero-porphyritic textures due to the aggregation of one, and those of more than one mineral.[1] In acid rocks the former are commonly a consequence of normal crystallization of the enclosing magma, whereas the latter represent, or are derived from, true xenoliths.

The glomero-granular texture is of significance in connexion with the origin of those granite-gneisses in which the foliation is due to a variation in the relative proportions of different constituents in different layers. Discussing the formation of gneiss from granite, Teall writes: 'Lenticular folia of quartz should alternate with corresponding folia of felspar; the grains of each separate folium representing collectively one of the larger individuals of the granular aggregate.'[2] A primary segregation of quartz and felspar in the granite would emphasize this tendency, and the larger folia commonly met with probably result from the metamorphism of glomero-granular rocks.

[1] Some authors use 'glomero-porphyritic' for monomineralic clusters, but this is not universal, neither is it the original sense in which the term was used by J. W. Judd (Quart. Journ. Geol. Soc. London, 1886, vol. 42, p. 71). A similar confusion exists regarding the term 'cumulophyric', which has been adopted for clusters of more than one mineral (A. Holmes, Petrographical methods, 1921, p. 343), although it was first applied to clusters of equant crystals (Cross, Iddings, Pirsson, and Washington, Journ. Geol. Chicago, 1906, vol. 14, p. 703).

[2] The geological structure of the north-west Highlands of Scotland. Mem. Geol. Survey, 1907, p. 65.





L. Hawkes: Partially fused Granite.

Explanation of Plate VII.

Partially fused granite from Kvosafoss, Iceland.

Fig. 1. Photograph of the polished rock. $\times 1\frac{3}{4}$.

Fig. 2. Photomicrograph showing elongated quartz aggregate in the middle. The boundaries of the felspar aggregates are marked in with black lines. The area between the two borders is groundmass. Ordinary light. $\times 8$.

Fig. 3. Irregular patches of quartz and felspar with groundmass between. Ordinary light. $\times 9$.

Fig. 4. Illustrates the segregation of the groundmass quartz at the phenocrystal quartz borders. Note the central small quartz separated from the felspar area by groundmass. Ordinary light. $\times 9$.

The occurrence of a mineral hitherto unrecognized in the phonolites of Dunedin, New Zealand.

(With Plate VIII.)

By Patrick Marshall, M.A., D.Sc., F.G.S.
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[Read June 11, 1929.]

THE phonolites which are found in the volcanic region of Dunedin, New Zealand, are of a varied character. Some of them are of ordinary types, but others are nephelinitoid, and some of them have sodalite in abundance. Besides the phonolites, there are trachydolerites, some of which also contain sodalite as well as nepheline. There is also an abundance of tinguaites, in all of which nepheline is distinct and sometimes sodalite as well. All petrologists who have worked in this region are therefore perfectly familiar with the minerals sodalite and nepheline in many different associations and conditions.

In the majority of the phonolitic rocks there is, in addition to the nepheline and sodalite, a mineral of ill-defined characters. This was at first considered to be allotriomorphic nepheline.[1] This opinion was based on the solubility of the mineral in acid and on the staining of the mineral with Prussian blue, after gelatinization. Recent examination of this mineral has shown that it cannot rightly be referred to nepheline or sodalite, but in composition and optical properties it approaches microsommite and davyne; though it differs from the former of these in having a far smaller percentage of chlorine, and from the latter in its smaller percentage of lime. It is proposed to call this mineral *ameletite* (from ἀμελής, neglected).

In the majority of trachytoid phonolites of this region, there is no nepheline or sodalite, but ameletite is abundant. In one of these

[1] P. Marshall, Quart. Journ. Geol. Soc. London, 1906, vol. 62, p. 402.

rocks—the trachytoid phonolite of Tainui quarry, Anderson's Bay—the mineral has now been found with a definite crystalline form, which makes it possible to give it a definition with greater precision than was possible when the interstitial occurrence alone was known.

The crystal sections are small, 0·15 mm. in diameter. The form is usually rectangular, like that of nepheline, and, as in that mineral, there are occasional hexagonal sections as well. There is a definite cleavage parallel to one pair of the sides of the quadrangular sections, but it is less distinct in the hexagonal sections. The refractive index is very low—less than that of anorthoclase—and far less, therefore, than that of nepheline, but higher than that of sodalite. The birefringence is 0·003, distinctly lower than that of nepheline, and of course much lower than cancrinite, from which in other respects also it is very different. In all of these characters of form and optical relations the mineral closely resembles microsommite; though it seems that microsommite has not been recognized as a normal rock-forming mineral.

It is most noticeable that this mineral is the first of all the constituents of a rock to be affected by the action of percolating water. The first effect is a slight staining by iron oxide. This is yellowish-green at first, but soon becomes yellow, and even brown; and this change in colour will take place without any of the nepheline or sodalite in a section being affected by the action of the solution. When once this fact has been recognized it is often easy to identify ameletite in a section, in the presence of the other minerals that have been mentioned. In the rock at Tainui quarry, as mentioned above, there is no nepheline or sodalite, but ameletite is in considerable quantity both as crystals and as interstitial material. Staining methods at once distinguished the mineral grains that are gelatinized by dilute acid. When these were closely examined it became certain that none of them could be referred to nepheline or sodalite.

A powdered sample of the rock from Tainui quarry was treated with dilute hydrochloric acid and warmed to 60° C. for ten minutes. It was found that 12·5 per cent. of the rock went into solution, and an analysis of this dissolved matter gave the results under I. Analysis II is of the 25·65 per cent. of material that was dissolved from another trachytoid phonolite from North Head, Otago Harbour, in which the same mineral is found more plentifully, though with less definite crystalline form. Analysis III is of the 21·35 per cent. of material dissolved from a trachytoid phonolite from Taipara,

Rarotonga Island, Cook Islands, South Pacific. It will be seen that there is a substantial agreement between these three analyses, which correspond approximately with a formula $12SiO_2.6Al_2O_3.9Na_2O.\frac{1}{2}NaCl$. But whether this actually represents the composition of ameletite must remain an open question for the present.

	I.	II.	III.	Micro-sommite.	Davyne.	Nepheline.	Sodalite.
SiO_2 ...	36·67	36·40	35·96	32·21	38·76	44·03	38·12
Al_2O_3 ...	34·70	34·70	34·11	29·22	28·10	33·28	31·68
CaO ...	1·80	2·49	2·12	12·60	9·32	1·77	—
Na_2O ...	24·18	24·90	23·03	10·14	15·72	15·44	24·37
K_2O ...	0·86	0·96	0·53	6·79	1·10	4·94	—
SO_3 ...	0·30	—	—	4·43	—	—	—
CO_2 ...	—	—	—	—	5·63	—	—
Cl ...	2·15	3·15	1·58	6·71	trace	—	6·69
	100·66	102·60	97·33	102·10	100·59 [1]	100·32 [2]	100·86

[1] Including H_2O 1·96. [2] Including H_2O 0·21, Fe_2O_3 and Mn_2O_3 0·65.
Analyses of microsommite, &c., quoted from Dana's 'System of Mineralogy'.

The percentage of silica is seen to be lower than the amount found in any of the felspar or felspathoid minerals in rocks. In order to be certain that all of the silica of the mineral matter that was attacked had gone into solution, the residue was boiled with caustic potash; but it was found that no more silica was dissolved. In the table given above, analyses of microsommite, davyne, nepheline, and sodalite are quoted for comparison. It is at once seen that the composition of the mineral matter, that was dissolved out of the rock, is notably different from that of the minerals quoted.

It has been previously stated that ameletite responds to the ordinary gelatinizing and staining methods of treatment in the same manner as nepheline and sodalite. A difference, however, is shown when sections of these alkali lavas are treated with dilute silver nitrate at ordinary temperature. Nepheline and sodalite are not affected by the nitrate; but ameletite speedily acquires a deep violet colour, which is caused by the formation of silver chloride. It is clear that in this mineral the chlorine is very loosely held in combination. It was surprising to find that when the powdered rock was boiled in water a considerable portion of the chlorine goes into solution. The treatment of a section with silver nitrate can, therefore, be used to distinguish ameletite from nepheline and sodalite, when other

methods fail, which is rarely or never the case if one has examined many slides that contain these three minerals. The readiness with which ameletite becomes stained by iron compounds is probably due to the action of the chloride, which is so readily evolved, on the iron carbonate or other compounds of iron which are formed in the soil, and are carried by percolation into the rock.

Ameletite, then, differs from nepheline in its lower refractive index, lower birefringence, content of chlorine, lower percentage of silica, prismatic cleavage, and natural staining with iron compounds. In the laboratory it can be distinguished by staining with silver nitrate solution. From sodalite it can be distinguished by the frequent rectangular sections, birefringence, and by its higher refractive index. Chemically it contains some lime and has far less chlorine than sodalite. Sodalite is far less easily stained by iron compounds in the rock and does not become stained with dilute silver nitrate solution. Microsommite and davyne appear to resemble ameletite closely in crystallographic and optical characters, though full descriptions of these in rock slices are lacking. Microsommite, however, contains more lime, potash, and chlorine, but notably less silica, alumina, and soda. Davyne, too, contains more lime, and has also a considerable percentage of carbon dioxide, which is not present in ameletite. On the other hand, davyne has no chlorine, and has much less soda. Ameletite is at once distinguished from cancrinite by its much lower birefringence.

In the Dunedin phonolites ameletite has a very general occurrence. It is found much more frequently than nepheline; and is still more common than sodalite, though that mineral is frequent in many of the rocks. Its occurrence explains the fact that all analyses of trachytoid phonolites from this locality show the presence of appreciable amounts of chlorine, though no sodalite could be found in them. The following may be quoted as typical analyses[1] of the Dunedin trachytoid phonolites:

[1] For analyses and descriptions of Dunedin phonolites, see:
P. Marshall, Geology of Dunedin (New Zealand). Quart. Journ. Geol. Soc. London, 1906, vol. 62, pp. 381–424.
C. A. Cotton, Geology of Signal Hill, Dunedin. Trans. N.Z. Inst., 1909, vol. 41 (for 1908), pp. 111–126.
J. A. Bartrum, Some rocks of Mount Cargill, Dunedin. Trans. N.Z. Inst., 1912, vol. 44 (for 1911), pp. 163–179.
P. Marshall, The sequence of lavas at the North Head, Otago Harbour, Dunedin (New Zealand). Quart. Journ. Geol. Soc. London, 1914, vol. 70, pp. 382–408.

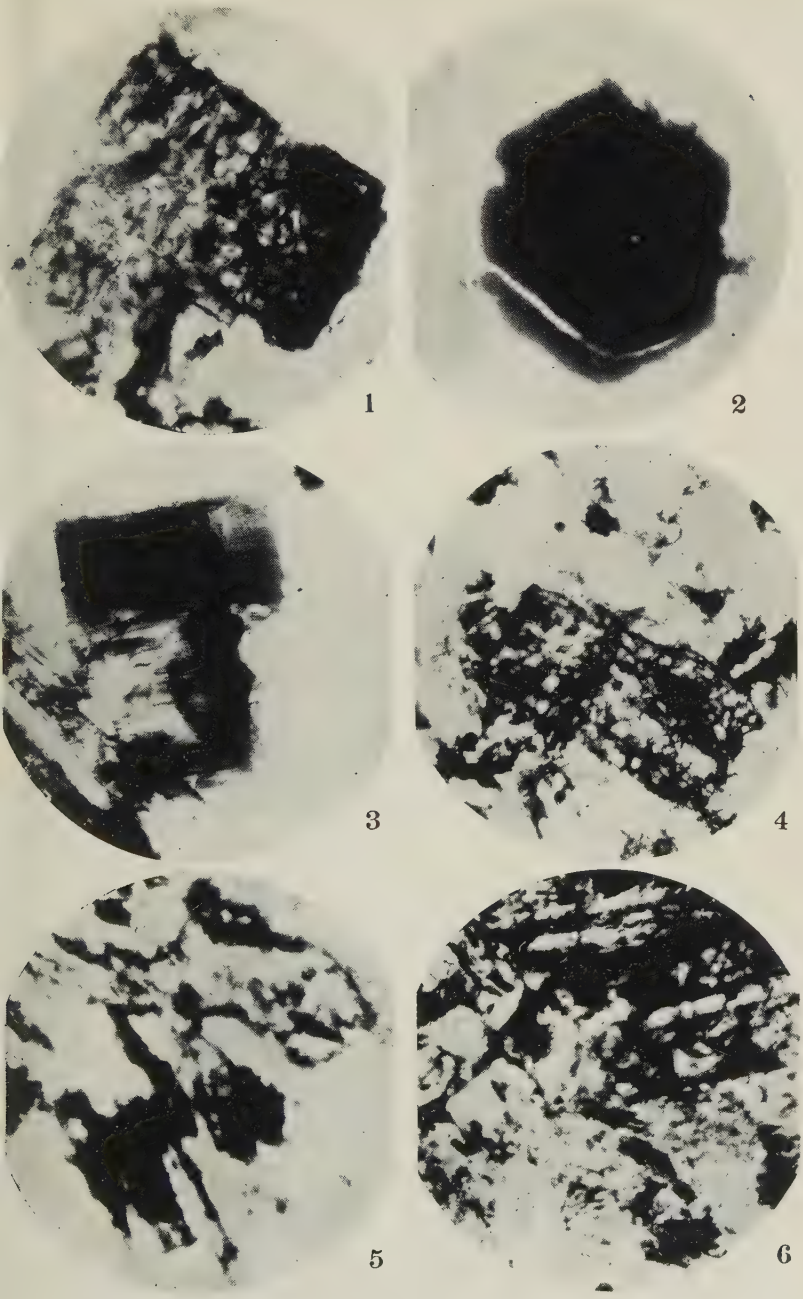
	SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MgO.	CaO.	Na_2O.	K_2O.	H_2O.	Cl.
I.	56·12	21·32	2·59	3·29	0·56	2·30	5·79	4·81	1·54	0·34
II.	54·15	16·09	7·35	4·90	1·61	3·86	5·94	4·41	1·40	0·40
III.	57·00	16·06	5·53	3·22	0·64	1·51	8·00	6·18	2·10	0·45

II, also TiO_2 0·41, P_2O_5 0·42. III, also TiO_2 0·39.

Ameletite is also quite frequent in rocks that contain either or both nepheline and sodalite. It occurs also in trachytoid phonolites of Rarotonga, Cook Islands, and of Huahine and Raiatea in the Society Islands, South Pacific. The very general record of chlorine in the analyses of trachytoid phonolites suggests that ameletite is not restricted to the Dunedin rocks.

Explanation of Plate VIII.

1. Trachytoid phonolite. Tainui quarry, Anderson's Bay, Dunedin, New Zealand. A crystal of ameletite stained naturally with ferric hydroxide. Rest of field felspar and irregular cossyrite. The ameletite shows two rectangular sets of cleavages. ×190.
2. Trachytoid phonolite. Tainui quarry. Crystal of ameletite stained deeply with natural deposit of ferric hydroxide. Rest of slice felspar, narrow prisms of aegirine, and grains of magnetite. ×190.
3. Trachytoid phonolite. Tainui quarry. Crystal of ameletite stained deeply by a natural deposit of ferric hydroxide. A prismatic cleavage is shown. Rest of field felspar prisms. ×190.
4. Trachytoid phonolite. Tainui quarry. Crystal of ameletite stained with dilute silver nitrate. Small crystals of aegirine, cossyrite, and magnetite; the rest felspar. ×110.
5. Trachytoid phonolite. Tainui quarry. Interstitial ameletite between felspar prisms. Stained with silver nitrate. ×190.
6. Trachytoid phonolite. Logan's Point, Dunedin, N.Z. The clearer half of the field shows aegirine and cossyrite in an unstained complex of felspar, nepheline, and ameletite. The darker half is stained with dilute silver nitrate. The photograph shows the deeply stained ameletite with laths of felspar and rectangles of nepheline. ×190.



P. Marshall: Ameletite in Phonolite from Dunedin, New Zealand.

Fülöppite, a new Hungarian mineral of the plagionite-semseyite group.[1]

By I. de Finály,
Royal Hungarian Geological Survey,
and Sándor Koch, Ph.D.
Hungarian National Museum, Budapest.

[Read June 11, 1929.]

In the Autumn of 1928 Dr. Béla Fülöpp and Mr. G. Kupás sent for examination an unknown mineral, which had been found in no. III level on the main lode of the Kereszthegy mine at Nagybánya, comitat Szatmár [now Baia Mare, Satul-Mare, Romania]. The small crystals show a close resemblance to those of plagionite from Wolfsberg in the Harz Mountains, but the results of our detailed examination prove that we have here a new mineral. For this we propose the name fülöppite in honour of Dr. B. Fülöpp, an enthusiastic collector of minerals and a generous patron of the Magyar Nemzeti Múzeum (Hungarian National Museum).

The crystals are usually about a millimetre across, and some up to 2 mm., but only the smaller crystals are suitable for goniometric measurement. Calculated from the measured angles

$(100):(111) = 59°\ 34'$, $(001):(111) = 41°\ 48'$, and $(111):(1\bar{1}1)$ $59°\ 20'$

the axial elements of the holohedral monoclinic crystals are

$$a:b:c = 1{\cdot}1087:1:0{\cdot}7011,\ \beta = 85°\ 15\tfrac{1}{2}'.$$

Eight forms, $c(001)$, $a(100)$, $d(\bar{1}01)$, $e(112)$, $p(111)$, $t(\bar{2}23)$,

[1] Read at the Hungarian Academy of Sciences, Class III (Natural History), on April 22, 1929. The mineralogical and crystallographic work was done by Dr. S. Koch in the Mineralogical-Petrographical Institute of the Pázmány Péter University, Budapest, and the chemical portion by I. de Finály in the Chemical Laboratory of the Royal Hungarian Geological Survey.

$o(\bar{1}11)$, $s(\bar{2}21)$, were observed on the crystals. Other measured angles are :

	Observed.	Calculated.		Observed.	Calculated.
$ac = (100):(001)$	85° 12′	85° 15½′	$tt' = (\bar{2}23):(\bar{2}\bar{2}3)$	47° 0′	47° 2½′
$a'c = (\bar{1}00):(001)$	94 50	94 44½	$oc = (\bar{1}11):(001)$	44 45	44 47
$dc = (\bar{1}01):(001)$	33 35	33 37	$oo' = (\bar{1}11):(\bar{1}\bar{1}1)$	63 30	63 5½
$ec = (112):(001)$	24 37	24 38	$od = (\bar{1}11):(\bar{1}01)$	31 49	31 32¾
$ee' = (112):(1\bar{1}2)$	36 20	36 2	$op = (\bar{1}11):(111)$	54 16	54 44
$tc = (\bar{2}23):(001)$	32 58	33 1½	$sc = (\bar{2}21):(001)$	64 10	64 33

The calculated angles for each of the eight forms to the three axial planes are given in the following table :

	Angle to		
	$a(100)$.	$b(010)$.	$c(001)$.
$c(001)$	85° 15½′	90° 0′	—
$a(100)$	—	90 0	85° 15½′
$d(\bar{1}01)$	118 52½	90 0	33 37
[abs. (110)]	47 51	42 9	85 42½
$e(112)$	69 18½	71 59	24 38
$p(111)$	59 34	60 20	41 48
$t(\bar{2}23)$	107 29½	66 29	33 1½
$o(\bar{1}11)$	114 18	58 27	44 47
$s(\bar{2}21)$	124 33½	47 54	64 33

The negative hemi-pyramids are the predominating forms, and give rise to a short-prismatic habit of the crystals. On this account the crystals have been drawn (except fig. 3) showing the back view with $a'(\bar{1}00)$ in front. Crystals of thick-tabular habit with the basal plane $c(001)$ largely developed are of rare occurrence; on such crystals the positive and negative hemi-pyramids are equally developed (fig. 3).

The larger crystals are always short-prismatic in habit, and usually show only the forms $c(001)$, $a(100)$, and $o(\bar{1}11)$ (fig. 1). The predominating faces of $o(\bar{1}11)$ are slightly concave and are heavily striated parallel to the intersection edge o/c. The well-developed faces of $a(100)$ are slightly convex and striated parallel to the intersection edge a/c. The small triangular faces of $c(001)$ are bright, but generally somewhat curved and give poor reflections. On some of the larger crystals the positive hemi-pyramid $p(111)$ occurs as narrow striated faces (fig. 2).

The smaller crystals are richer in faces, which are generally brighter, though still sometimes slightly curved and more or less striated. Most of these crystals are also of the short-prismatic habit (fig. 4) and only a few of the thick-tabular habit (fig. 3). On seven

of the smaller crystals measured on the goniometer the forms *c a e p t o* are present on all; the rarer form *d* ($\bar{1}01$) was present on three of these crystals, and *s* ($\bar{2}21$) on only one. The best reflections are given by the small rhomb-shaped faces of *c* (001) and by the positive hemi-pyramids *p* (111) and *e* (112). The narrow faces of

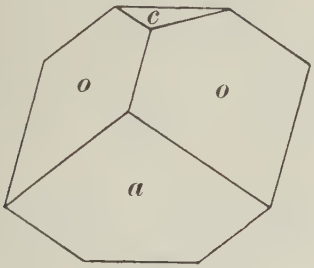


Fig. 1.

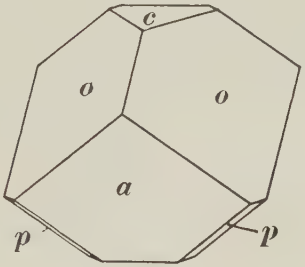


Fig. 2.

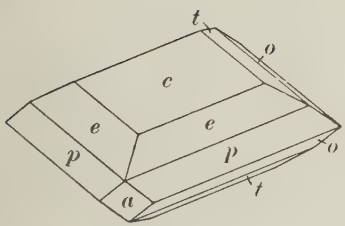


Fig. 3.

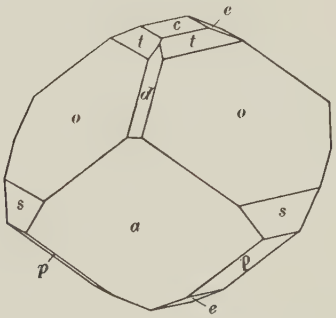


Fig. 4.

Crystals of fülöppite. [*a'* ($\bar{1}00$) in front in figs. 1, 2, and 4.]

d ($\bar{1}01$) also give good reflections. *a* (100) is curved and striated. The worst reflections are those from the curved and striated negative hemi-pyramids.

No twinned crystals or parallel overgrowths were observed. Groups consist of individual crystals irregularly grown over one another.

The mineral is brittle with uneven fracture and shows no cleavage. The smaller crystal faces show a lead-grey colour with bright metallic lustre, and the striated faces a steel-grey with feeble lustre. The mineral sometimes shows a steel-blue, or less often a bronzy, tarnish. The streak is reddish-grey and the hardness rather greater than 2.

The mineral is readily fusible before the blowpipe, and gives yellow and white deposits on the charcoal. It melts easily in the open tube, yielding sulphurous vapours and a deposit of Sb_2S_3. It is not attacked by concentrated hydrochloric nor by concentrated nitric acid.

A small crystal was embedded in sealing-wax and polished for metallographic examination. It was very soft and polished easily to a brilliant white surface. This surface was treated with various reagents. Negative results were obtained with HNO_3 (1 : 1), HCl (1 : 1), KCN (20 %), $FeCl_3$ (20 %), and $HgCl_2$ (5 %). With KOH (40 %) acting for 60 seconds a slight brown tarnish was formed, which was easily wiped off with a wet rag, the mineral not being attacked. With aqua regia a brownish-yellow, later bluish, tarnish is developed in 20 seconds; this can be rubbed off, the surface then being grey. After longer action (50–60 seconds) the mineral becomes dark grey with here and there minute yellowish specks.

The specific gravity was determined in a small pyknometer on the carefully selected crystals used for the chemical analysis and weighing 0·3052 gram. The result, 5·24, when corrected is $D_4^{20} = 5·23$.

The qualitative analysis showed the presence of lead, antimony, and sulphur. Lead and antimony were estimated in one portion (0·1606 gram) of the material which was decomposed in a current of chlorine.[1] The lead chloride was washed out with warm water and the lead precipitated and weighed as $PbSO_4$.[2] Antimony was precipitated by hydrogen sulphide and after heating in a current of carbon dioxide weighed as Sb_2S_3.[3] Sulphur was estimated in a separate portion (0·0368 gram) according to the method of Fresenius,[4] with the precautions and corrections prescribed by Winkler.[5] The following results were obtained:

		Atomic ratios.		Calculated for $Pb_2Sb_6S_{11}$.
S	24·10 %	0·7524	11·01	23·56
Sb	47·50	0·3904	5·71	48·78
Pb	28·29	0·1367	2	27·66
SiO_2	0·19	—	—	—
	100·08			100·00

[1] F. P. Treadwell, Kurzes Lehrbuch anal. Chem., 1922, vol. 2, p. 307.

[2] L. W. Winkler, Zeits. angew. Chem., 1922, vol. 35, p. 662.

[3] F. P. Treadwell, loc. cit., vol. 2, p. 180.

[4] F. P. Treadwell, loc. cit., vol. 2, p. 306.

[5] L. W. Winkler, Zeits. angew. Chem., 1917, vol. 30, p. 251; 1920, vol. 33, pp. 59, 159.

Although the antimony is rather low, the chemical composition of fülöppite may therefore be expressed by the formula

$$Pb_2Sb_6S_{11} \text{ or } 2PbS.3Sb_2S_3.$$

Fülöppite differs from the other members of the plagionite-semseyite group in containing antimony sulphide in molecular excess over lead sulphide, and it is one of the few known acid sulphantimonites.

The data obtained give some support to the suggestion made by L. J. Spencer[1] that these minerals form a morphotropic series. With increasing lead there is an increase through the series in the length of the *c*-axis whilst the *a*-axis remains practically unchanged.

			a : *b* : *c*.	*β*.
Fülöppite,[2]	$3PbS.4Sb_2S_3$	...	1·1087 : 1 : 0·7011	85° 15½′
Plagionite,[3]	$5PbS.4Sb_2S_3$	...	1·1305 : 1 : 0·8422	72 45
Heteromorphite,	$7PbS.4Sb_2S_3$	...	—	—
Semseyite,[4]	$9PbS.4Sb_2S_3$	...	1·1356 : 1 : 1·0218	74 14

Fülöppite usually forms crystals of short prismatic or rhombohedral habit; plagionite forms small crystals of tabular habit; and semseyite assumes a tabular or prismatic habit.

Another lead antimony mineral is present in intimate association with the fülöppite. This forms radiating or globular groups of fine needles of a steel-grey to black colour with feeble metallic lustre and sometimes a blue tarnish. Some hairs of plumosite are perhaps also present. The acicular mineral is brittle with uneven fracture, dark grey streak, and hardness about 2. The very thin needles yielded no results on the goniometer. Specific gravity 5·23, corrected $D_4^{20} = 5·22$. Analysis gave the following results:

		Atomic ratios.		Calculated for $Pb_3Sb_8S_{15}$.
S	23·10 %	0·7306	15·27	23·17
Sb	46·17	0·3844	8·04	46·91
Pb	29·33	0·1436	3	29·92
Fe	0·08	—	—	—
SiO_2	0·94	—	—	—
	99·62			100·00

Formula $Pb_3Sb_8S_{15}$ or $3PbS.4Sb_2S_3$. The small excess of sulphur shown in the atomic ratios can be explained by the presence of a few

[1] L. J. Spencer, Min. Mag., 1899, vol. 12, p. 55.

[2] The analysis is actually between $3PbS.4Sb_2S_3$ and $2PbS.3Sb_2S_3$., as may be seen from the calculated values for the formula given below.

[3] Axial ratios of F. Zambonini, Rivista Min. Crist. Ital., 1912, vol. 41, p. 21.

[4] Axial ratios of G. F. H. Smith. Min. Mag., 1919, vol. 18, p. 357.

minute crystals of sulphur adhering to the needles. This mineral, with practically the same chemical composition as fülöppite, is also an acid sulphantimonite of lead. The analyses of both give percentages of lead and antimony between the limits required of the formulae $2PbS.3Sb_2S_3$ and $3PbS.4Pb_2S_3$. With the presence of some plumosite (or even possibly stibnite [1]), as noted above, the formula is open to some doubt. From the acicular habit of the crystals the mineral may be presumed to be orthorhombic, and it is provisionally referred to keeleyite, a mineral recently described by S. G. Gordon [2] from Oruro, Bolivia, to which he gave the formula $2PbS.3Sb_2S_3$. Later examinations [3] of keeleyite suggest, however, that it is identical with zinckenite $PbS.Sb_2S_3$.

Other minerals present on the fülöppite specimens are dark brown blende, small quartz crystals, a few small brown rhombohedra of dolomite, and a few minute crystals of sulphur.

[1] L. J. Spencer, Note on 'feather-ore' . . . Min. Mag., 1907, vol. 14, p. 207.

[2] S. G. Gordon, Proc. Acad. Nat. Sci. Philadelphia, 1922, vol. 74, p. 101 [Min. Abstr., **2**–11].

[3] E. V. Shannon and M. N. Short, Amer. Min., 1927, vol. 12, p. 405; E. T. Wherry, ibid., 1928, vol. 13, p. 29 [Min. Abstr., **3**–453].

Bismutotantalite, a new mineral, from Uganda.

By E. J. Wayland, A.R.C.S., M.I.M.M.
Director, Geological Survey of Uganda,
and L. J. Spencer, M.A., Sc.D., F.R.S.
Keeper of Minerals, British Museum of Natural History.

[Read June 11, 1929.]

1. *Discovery.*—The discovery of tin-ore in Ankole (south-western Uganda) led to a great deal of prospecting on the part of qualified and unqualified, experienced and inexperienced, individuals, not only in the vicinity of the original discoveries, but also in many other parts of the Protectorate. One of the results of this activity was the finding, by a prospector, of a deposit of alleged coal at a spot rather less than 25 miles WNW. (approx.) of Kampala and about 35 miles NW. of Entebbe. With reference to this, the discoverer was told by the Geological Survey that his hoped-for fuel was in reality tourmaline, but inasmuch as it was associated with a pinkish-buff mica characteristic of the stanniferous pegmatites of Ankole, further search might disclose the presence of tinstone.

Some laboratory tests subsequently made by the writer on the supposed coal-bearing rock, proved it to contain a little finely divided cassiterite, and partly in consequence of this some field assistance was given to the prospector, who was advised to put down a trial hole at a spot where it was anticipated that a pegmatite would be revealed near the surface; for, on analogy with some occurrences elsewhere, it was deemed not altogether unlikely that, if found, the pegmatite would prove to carry tin. A pegmatite was struck; moreover it was found to be metalliferous, but the ore it carried was not that of tin. It was found to be decidedly heavy (specific gravity rather more than 8); moderately hard (H. $5\frac{1}{2}$ approx.); grey-black to pitch-black in colour, except for some thin yellowish to pinkish veinlets running through it or coating it in places; and without cleavage, except for parting planes. It was a puzzling mineral, and none of us could name it at sight, though it suggested tantalite more than anything

else. Such tests as could be applied at the time more or less convinced us that we had a new mineral to deal with; and for convenience, and pending a detailed knowledge of its nature, we referred to it as 'ugandite'. E. J. W.

2. *Preliminary Analysis.*—At the time of the discovery of this new mineral our laboratory was out of action, being in the hands of the Public Works Department, and possessing but three walls and half a roof; but Mr. W. C. Simmons, Chemist and Petrologist to the Survey, concluded, as a result of such investigations as he was able to make under trying and difficult circumstances, that the new mineral was in all probability a tantalate of bismuth—a compound with which mineralogists were hitherto unacquainted. Its crystallography, however, was not determinable from the samples available. An attempt to discover, by photographic methods, whether the new mineral was perceptibly radioactive or not, gave a negative result. The same may be said of similar experiments carried out in the Geophysical Laboratory at Washington, by Dr. C. N. Fenner, and by the chemists of the Imperial Institute in London; but Professor Arthur Holmes informs me that a specimen submitted to him proved to contain radioactive streaks. E. J. W.

3. *Occurrence and Geological Setting.*—The site of the discovery is a place called Gamba Hill (32° 10′ E., 0° 30′ N.) in Busiro County, lying between the Kampala–Mubendi and the Kampala–Hoima roads, and to the north of the Myanja river at the junction of Native-owned and European-owned lands, and just within the latter. Topographically the area lies within the limits of the well-developed Buganda peneplain. The solid geology is greatly obscured by elephant-grass, surface soils, and lateritic ironstone, and is but little known. In the vicinity, however, it consists essentially of mica-schists belonging, it is believed, to the basal (pre-Cambrian) complex, intruded by acid dikes, a few of which are highly tourmalinized (quartz-tourmaline- or tourmaline-quartz-rocks), but most of which are quartz dikes and more normal pegmatites. It is, according to Mr. Simmons, in an irregular pipe-like intrusion of the latter (consisting of quartz, felspar—often highly kaolinized—and mica, as very large crystals) that the bismuth mineral has been found. A characteristic feature of the pegmatite appears to be the occurrence of large buff-coloured flakes of muscovite that resemble leaves, owing to the presence of what appears to be a twin-plane across the centre of the

flakes, thus separating two systems of parallel striations that impinge upon each other like the limbs of chevrons. The limits of the pegmatite are (or were a month or two ago) unknown, and the whole is covered by 6 to 8 feet of surface soil and quartz rubble. The mineral occurs as large misshapen crystals up to several pounds in weight, and its distribution seems to be patchy and irregular. Too little is known at present to permit one to say whether any persistent body of ore is likely to be found or not. It is most probable, however, that well-directed search will reveal other and similar dikes; and the possible presence of other minerals in the neighbourhood must not be overlooked. It might be mentioned in passing that colours of gold have been found in the alluvial deposits of the Myanja river in this area. E. J. W.

4. *Chemical Composition.*—Two chemical analyses were made at the Imperial Institute and are here published by permission of the Director. They were made by Mr. W. O. R. Wynn, and the mineralogical observations made on the same material by Mr. G. E. Howling are also recorded below. Another analysis was made by a commercial firm and I have permission to publish the results.

The average of the three analyses gives for the mineral rather more than 50 % of bismuth oxide, and about 47 % of tantalic and niobic oxides, which confirms Mr. Simmons's results, and shows the mineral to be chemically analogous with stibiotantalite. For this reason the tentative name of 'ugandite' has been abandoned and *Bismutotantalite* has been adopted in its stead.

The following is taken from the report furnished by the Imperial Institute:

'Two pieces of the new bismuth mineral which differed somewhat in lustre and shape were selected for analysis and specific gravity determinations. One (*a*) was an irregular, lustrous lump, the other (*b*) was tabular and somewhat duller in appearance. These were broken up and carefully freed as far as possible from adherent gangue, the chemical analyses, specific gravities, and the optical observations being made on the cleanest material obtainable.

'Very thin flakes under the microscope were brownish and translucent, but tapered away and became on the thinest edges smoke-grey to almost colourless and transparent. Optical observations with high power on these thin edges gave the following results: Birefringent, extinction parallel to elongation of fragments and to straight

edges when present; refractive index very high and greater than 2·2. The mineral may be orthorhombic.

'The specific gravities of the two selected pieces were (*a*) 8·44, and (*b*) 8·03. The results of a fairly complete analysis of (*a*) and of a partial analysis of (*b*) are given as follows:

		Large fragment (*a*).	Small fragment (*b*).
Bismuth oxide,	Bi_2O_3 ...	52·26°	49·86°
Tantalic oxide,	Ta_2O_5 ...	40·12	41·15
Niobic oxide,	Nb_2O_5 ...	6·63	6·46
Manganous oxide,	MnO ...	0·12	0·12
Ferric oxide, Alumina,	Fe_2O_3, Al_2O_3 ...	0·11	0·30
Zirconia,	ZrO_2 ...	trace	—
Titanium dioxide,	TiO_2 ..	trace	—
Stannic oxide, Antimony oxide,	SnO_2, Sb_2O_3 ...	0·04	—
Rare earths,	ThO_2, &c. ...	not detected	—
Uranoso-uranic oxide,	U_3O_8 ...	not detected	—
Loss on ignition	...	0·33	1·05
		99·61	98·94

'It will be seen from the above chemical analyses that the two fragments were closely similar in composition, but that in specimen (*b*) the ratio of bismuth oxide to the oxides of niobium and tantalum was somewhat lower than in specimen (*a*). The analysis of sample (*a*), which consisted of somewhat fresher looking material than sample (*b*), when calculated to a 100 % basis and neglecting impurities gave the following results:

Bismuth oxide, Bi_2O_3	52·78 %
Tantalic oxide, Ta_2O_5	40·52
Niobic oxide, Nb_2O_5	6·70

'This composition corresponds very closely with that required by the formula $Bi_2O_3.(Ta,Nb)_2O_5$. So far as can be ascertained no mineral having the chemical and physical characters of this black mineral from Uganda has been previously described.—28*th March*, 1929.'

The other analysis referred to above was reported as follows. In this analysis the tantalum and niobium were separated by the selenium oxychloride method:

Bi_2O_3.	Ta_2O_5.	Nb_2O_5.	SiO_2.	Fe_2O_3 and Mn_3O_4.	Total.
50·46	31·14	14·76	2·16	1·36	99·88

E. J. W.

5. *Crystallography and other Physical Characters.*—Specimens of the new mineral, generously sent by the Director of the Geological Survey

of Uganda for preservation in the British Museum collection, include some of the best and largest crystals yet found. These had been selected from large quantities (about 200 lb.) of the mineral, and they range in size from $2 \times 1\frac{1}{2} \times 1$ cm. to $10 \times 6 \times 6$ cm., the latter weighing 1,058 grams. A further lot of material, kindly furnished for study by Mr. Bruce Taplin, of Minerals Separation, Limited, consists of a number of fragments showing indications of crystalline form, which had been selected from a 30 lb. parcel of the picked ore. Finally, a small lot of specimens more recently presented to the Museum by Mr. G. C. Barnard, contained the best crystal of all.

Unfortunately, all these crystals and fragments are very irregularly bounded by rough and weathered surfaces, and they are not suitable for any precise determination of the crystallographic characters. Some of the specimens show a good parting in one or generally two directions; the two partings, when both present, being of equal quality. Such specimens show a lamellar structure with steps on the broken surfaces. Between these steps the mineral breaks with a sub-conchoidal fracture without any indications of cleavage. The surfaces of the partings are tolerably smooth and bright, sufficient to give approximate measurements on the reflecting goniometer. The mean of many readings of the angle between the two sets of parting is 82° 42′, with a range of 82° to 83°. A third much less distinct parting at approximately 90° to the other two is only rarely evident. These partings were of great assistance in orientating the irregular and misshapen crystals, and they suggest that the mineral may be orthorhombic.

The crystal ($4 \times 2\frac{1}{2} \times 2\frac{1}{4}$ cm.) presented by Mr. G. C. Barnard is more regularly developed. It is short-prismatic in habit, with some resemblance to columbite. This crystal (fig. 1) shows no partings, but the single well-formed face δ (011) has the same direction as one of the better partings on other crystals. With this orientation the third parting previously mentioned then becomes a (100). Measurement with the contact-goniometer gave the following angles (the angle $\delta\delta' = 97° 18'$ being the value determined from the parting planes on other crystals):

	Measured.	Calculated.	Stibiotantalite.
$mm''' = (110) : (1\bar{1}0)$ ...	76°	—	77° 18′ m (110)
$gg' = (130) : (\bar{1}30)$ ...	47	46° 12′	45 16 g (130)
$ww' = (133) : (\bar{1}33)$ ...	36	35 30	34 38 w (4.12.9)
$ww''' = (133) : (1\bar{3}3)$ ...	93	91 16	91 6 w (4.12.9)
$\delta\delta' = (011) : (0\bar{1}1)$ ...	97 18′	—	96 48 δ (043)
$gx = (130) : (141)$ ...	13	13 2	—

The axial ratios calculated from these angles are:

$$a : b : c = 0{\cdot}7813 : 1 : 1{\cdot}1363.$$

The lower end of this crystal is rounded, and shows indications of pyramids in the zone [110,001]. Several indefinite rounded faces are present on other crystals; but, in addition to the five forms noted above, only a (100) and k (103) were determined with certainty. Some of the rough planes on the crystals are perhaps only surfaces of contact with the other minerals in the pegmatite.

Forms of Bismutotantalite and the normal angles of each to the three axial planes.

Forms.	Angle to a (100).	Angle to b (010).	Angle to c (001).
a (100)	—	90° 0′	90° 0′
m (110)	38° 0′	52 0	90 0
g (130)	66 54	23 6	90 0
δ (011)	90 0	41 21	48 39
k (103)	64 8	90 0	25 52
w (133)	72 15	44 22	51 1
x (141)	72 39	21 15	78 7

As shown in the first table above, the angles of bismutotantalite correspond very closely with those of stibiotantalite. When δ (011) is given the indices (043), as was done by Penfield and Ford [1] for stibiotantalite, the axial ratios for both minerals show a close relation to those of columbite and tantalite. With this change in the axial ratios from those here adopted for bismutotantalite, the common form w (133) becomes (4.12.9), and x (141) becomes (4.16.3). It must be remarked that the values for bismutotantalite are only approximate and will need revision when better crystals are available.

		a : b : c.
Bismutotantalite,	$Bi_2O_3.Ta_2O_5$	0·7813 : 1 : 0·8522
Stibiotantalite,	$Sb_2O_3.Ta_2O_5$	0·7995 : 1 : 0·8448
Tantalite,	$FeO.Ta_2O_5$	0·8285 : 1 : 0·8898

The crystals are sometimes fractured and penetrated by narrow irregular veinlets from the matrix. This suggests a cause for the development of the planes of parting. The material is pitch-black with sub-metallic lustre, but on some crystals the black is mottled with areas of a pinkish-yellow colour with dull lustre, while a few smaller

[1] S. L. Penfield and W. E. Ford, Amer. Journ. Sci., 1906, ser. 4, vol. 22, p. 61.

and fragmentary crystals consist entirely of this material. A fragment parallel to a plane of parting, and showing the black and pink areas with a sharp dividing line, was ground down as thin (40 μ) as possible without tearing up. The pinkish-yellow material was then translucent and cloudy and appears to be mainly isotropic with some

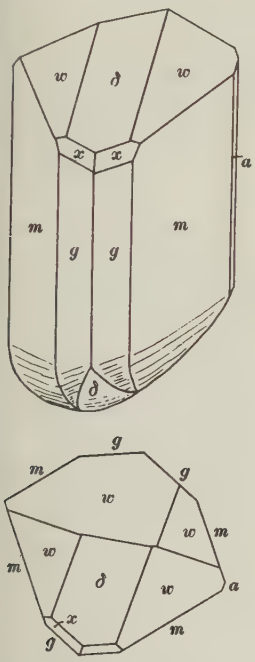


Fig. 1. Crystal of bismutotantalite. Clinographic drawing with the *b*-axis in front; and plan.

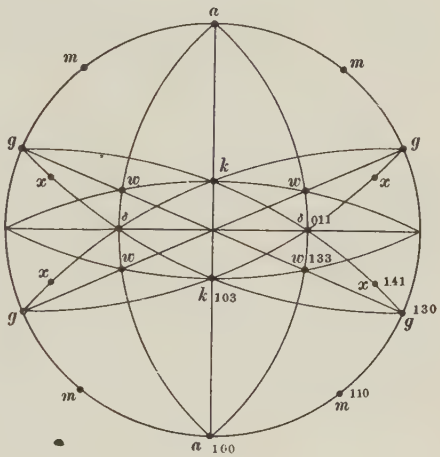


Fig. 2. Stereographic projection of the forms of bismutotantalite.

birefringent flakes or grains; but the black mineral remained quite opaque. In this thin section both areas show a rectangular network (parallel to the other two partings): in the meshes of the pink portion there are small particles of the unaltered black mineral; and in the black portion the network is marked out by veinlets and nodes of the pink material. The pink material is evidently an alteration product of the bismutotantalite. Heated in a bulb-tube it gave off abundant water and became yellow.

Analyses made by Mr. Max H. Hey in the Mineral Department of

the British Museum on separate portions of the pink mineral gave the following results:

	Bi_2O_3.	$(Ta,Nb)_2O_5$.	Fe_2O_3.	SiO_2.	H_2O.	Total.	Sp. gr.
I.	32·93	64·31	0·42	1·19	2·01	100·86	—
II.	42·82	52·13	0·64	0·62	2·10[1]	98·31[1]	—
III.	24·05	62·88	0·71[2]	2·00	8·65	98·29	6·99

[1] Water probably low. [2] $Fe_2O_3+Mn_3O_4$ 0·71.

He reports that the pink mineral is finely granular and consists of a mixture of optically isotropic and strongly birefringent materials. The mineral is not attacked by hydrochloric or nitric acids; but it is decomposed by hydrofluoric acid, bismuth going into solution and the tantalic acid remaining insoluble.

The black bismutotantalite finely crushed in oil was also examined optically by Mr. Hey. Very thin splinters are transparent and smoke-grey to colourless. The fragments give straight extinction and are optically biaxial. The refractive index is very high and the birefringence about 0·1 to 0·15. Specific gravity 8·15. Hardness about 5. Streak black. Not attacked by acids (HF, &c.).

The bismutotantalite was tested for pyro-electricity, but with negative results. [Some very remarkable pyro-electric effects were obtained by Penfield and Ford on crystals of stibiotantalite.]

L. J. S.

The variation of optical properties with chemical composition in the rhodonite-bustamite series.

By Max H. Hey, B.A., B.Sc.

Assistant-Keeper in the Mineral Department of the British Museum of Natural History.

[Read November 5, 1929.]

A SPECIMEN of hardystonite from Franklin Furnace, New Jersey, U.S.A., purchased in 1899 from Mr. W. M. Foote of Philadelphia for the British Museum collection consists largely of an associated pale pink mineral which has at various times been thought to be rhodonite, fowlerite, wollastonite, or scapolite. This specimen has recently again attracted attention because of the remarkable fluorescent effects it shows in ultra-violet rays. The pink mineral displays a bright brick-red fluorescence, the hardystonite a violet; and some willemite present fluoresces a brilliant green. A description in the literature of such a mineral from Franklin Furnace being unknown to Dr. L. J. Spencer, he handed over to me the problem for investigation, and a detailed examination has proved the pink mineral to be bustamite.

This bustamite is evidently very different in appearance, as in its associated minerals, from the bustamite recently described from Franklin Furnace by J. V. Lewis and L. H. Bauer [1] or by E. S. Larsen and E. V. Shannon,[2] and indeed from any bustamite hitherto recorded from other localities. A more precise determination was therefore made of the optical constants, and the investigation has been extended to other members of the rhodonite-bustamite series, between the extreme members of which a continuous variation has been traced.

[1] J. V. Lewis and L. H. Bauer, Amer. Journ. Sci., 1922, ser. 5, vol. 4, p. 249 [Min. Abstr., **2**–192].

[2] E. S. Larsen and E. V. Shannon, Amer. Min., 1922, vol. 7, pp. 95, 149 [Min. Abstr., **2**–362, 472].

Experimental.

The specimen (I) from Franklin Furnace (B.M. 84606) is a cleavage slab measuring 9 by 7 cm. of the pale pink mineral, which is veined with finely granular white hardystonite. It also shows spots of pale grey willemite, hardly distinguishable in ordinary light, but standing out magnificently under ultra-violet illumination, and a few minute specks of franklinite.

Two other specimens were chosen for examination; one was a specimen (III) from the Harstig Mine, Pajsberg, Sweden (B.M. 68037) showing small bright red crystals of the habit described by G. Flink [1] for rhodonite from this locality (that is, acute wedges formed by large faces of M ($1\bar{1}0$) and k ($\bar{2}21$), with q (221), c (001), and n ($\bar{2}\bar{2}1$) small) on massive iron-schefferite. This specimen was bought of Mr. Flink in 1892, and may fairly be assumed to be similar to the material that he had examined. The other (II) is a cleavage slab, 10 by 6 cm., of brownish-red rhodonite, with garnet, from Långban, Sweden (B.M. 43473). There was no difficulty in obtaining pure material for analysis from any of the specimens; with the first, from Franklin Furnace, a final selection was made under the ultra-violet lamp to ensure perfect freedom from hardystonite and willemite, but this aid could not be employed with the other specimens, as they showed little or no fluorescence under ultra-violet rays. Density determinations were made in carbon tetrachloride by the pyknometer, and are given below along with the analyses.

	I. Franklin Furnace.	II. Långban.	III. Harstig mine, Pajsberg.
SiO_2	47·68 %	47·69 %	46·33 %
Al_2O_3	0·25	0·43	0·26
Fe_2O_3	0·06 [1]	0·05	0·83 [1]
FeO	n.d.	1·93	n.d.
MnO	27·65	32·93	44·28
ZnO	0·26	0·07	0·07
MgO	0·03	0·02	0·04
CaO	24·86	15·24	8·02
Ignition ...	0·06	0·29	0·22
	100·85	98·65 [2]	100·05
Sp. gr. ...	3·302±0·01	3·418±0·01	3·615±0·03

[1] Total iron as Fe_2O_3. [2] Also some alkalis, not determined.

[1] G. Flink, Zeits. Kryst. Min., 1886, vol. 11, p. 518.

Or, in molecular proportions, expressed so that the sum of the monoxides (MnO, FeO, ZnO, CaO, MgO) is 100 :

	I.	II.	III.
SiO_2	94·15	103·88	100·25
FeO	n.d.[1]	3·51	n.d.
MnO	46·55	60·74	81·15
ZnO	0·38	0·11	0·12
MgO	0·09	0·07	0·14
CaO	52·98	35·57	18·59

[1] Less than 0·08 as calculated from the total iron.

For optical examination, a cleavage flake from each specimen was mounted in Canada balsam after being definitely oriented by measurement on the goniometer. The flakes were of different orientations, and for comparative purposes the results of measurement on the Fedorov universal stage were plotted directly on a stereographic net, and then projected on b(010), with a'($\bar{1}$00) at $\phi = 0°$; so plotted, the poles of the three principal planes lie at the following positions for red and for green light:

		I.		II.		III.
		Red.	Green.	Red.	Green.	Red and Green.
α	ϕ ...	354°	353½°	357°	357°	350°
	ρ ...	83	83	80	80	83
β	ϕ ...	252	247	244	246	249
	ρ ...	29	21	24	25	30
γ	ϕ ...	88	86½	91	91	86
	ρ ...	62	70	69	67	61

The migration-paths of the three poles for the increase in manganese content from I to III are very peculiar, and quite different for different wave-lengths. They are plotted in fig. 1. The great dispersion of the bisectrices is very striking in the Franklin Furnace material (I), and has vanished within the accuracy of measurement in the Harstig material (III).

The refractive indices of all three specimens for sodium-light were determined by the immersion method, with the following results (all $\pm$0·003):

	I.	II.	III.
α	1·664	1·695	1·720
β	1·675	1·703	1·725
γ	1·679	1·710	1·733
$(\beta-1)/d$ ...	0·2044	0·2057	0·2005

Approximate values for the optic axial angles of I and III were obtained on the Fedorov stage, the former by extinction trials in known directions, the latter by direct location of one of the optic axes; for II, an optic axial angle could not be obtained by this method, but when the section, parallel to $M(1\bar{1}0)$, used for the Fedorov stage measurements was examined in convergent light, using an oil-immersion objective, an optic axis was observed on the border of the field, and the position approximately measured, so that it could be plotted. The values obtained agree well with those obtained from the measured refractive indices. The optical sign of all three specimens was carefully tested, and it was found that the Harstig material with a lime content about 8 %, an ordinary rhodonite (pajsbergite), is optically positive. This is in agreement with the results of A. Des Cloizeaux,[1] and not with the usually accepted conclusions of G. Flink. On the other hand I and II are negative. The extinctions were also measured on several faces, and agree well with the values obtained graphically from the other optical data.

	I.	II.	III.
2V	50–55°	84° approx.	75° approx.
Optical sign	Negative.	Negative.	Positive.
Extinction on:			
m to edge [*m* : *b*] ...	10–15°	20°	24°
M to edge [*M* : *b*] ...	± 0	—	15
b to edge [*b* : *M*] ...	3	0–3	—
a to edge [*a* : *b*] ...	—	—	30

The Franklin Furnace material shows three good cleavages, *b* (010), *m* (110), and *M* $(1\bar{1}0)$, and a poor one, *a* (100), all in one zone; the Långban material shows good cleavages parallel to *m* and *M*, less perfect to *b*, and possibly an imperfect cleavage *c* (001); the Harstig material, finally, shows good cleavages *m* and *M* and less perfect *c*. Clearly, with a fall in calcium content, the *c*-cleavage develops and the *b*-cleavage drops out.

The goniometric measurements made for the purpose of orienting the fragments used for optical study revealed a quite appreciable variation in the angles with the lime content; while the angles on the Harstig material agreed closely (as was to be expected) with Flink's figures, those for the Franklin Furnace mineral differed by as

[1] A. Des Cloizeaux, Bull. Soc. Min. France, 1884, vol. 7, p. 72.

much as a degree; accurate measurements were not obtained on the Långban material.

Harstig.—*Mc* 86° 36′ (Flink, 86° 24′); *M′k* 31° 13′ (Flink, 31° 13½′). Franklin Furnace material gave *bM* 40° 2′, *bm* 45° 14′, *ba* 94° 43′; or after adjustment by the cotangent formula, *bM* 40° 2′, *bm* 44° 45′, *ba* 95° 11′, while Flink gives for Harstig rhodonite *bM* 41° 38′, *bm* 45° 53′, *ba* 94° 26′. E. S. Larsen and E. V. Shannon found for a Franklin Furnace bustamite of very nearly the same composition as the present material: *bM* 40° 7′, *bm* 44° 58′, *ba* 94° 33′; or after adjustment by the cotangent formula, *bM* 40° 21′, *bm* 44° 44′, *ba* 94° 47′.

FIG. 1. Stereographic projection showing the principal optical directions of bustamite (I and II) and rhodonite (III), for red and for green light.

Correlation of data with those of other observers.

A certain number of data on the physical constants of rhodonite and bustamite and allied species have been obtained by previous workers, and it appeared of interest to see how far the extended data

will enable us to trace any regularities in the variation of the optical and other physical properties with the chemical composition. On the whole, an excellent agreement with the present results is obtained, and several of the physical properties appear to vary with the calcium content according to a simple linear relation.

In only one case are data for the complete location of the optical ellipsoid available. G. Flink (loc. cit.) determined the position of the optical ellipsoid for unanalysed rhodonite from the Harstig mine, Pajsberg, by a method of trial and error. The material was from the same locality as the analysed specimen III above, so it may probably be taken that it was about of the same composition. Unfortunately, Flink's extinction-angles disagree considerably with the position he assigns to the optical ellipsoid, and probably both his extinction-angles and ellipsoid orientation must be taken as approximate only. They agree roughly with the present values, within about the same degree of accuracy as that with which they agree among themselves. His extinction-angles are:

On M, 17° 6′ to $[Ma]$ in the acute angle $[Mc]:[Ma]$.
On a, 32° 26′ to $[ab]$ in the acute angle $[ab]:[ac]$.
On b, 10° 48′ to $[ab]$ in the obtuse angle $[ab]:[bc]$.
On c, 54° 26′ to $[cm]$ in the obtuse angle $[cm]:[cM]$.

The axial angle he found to be 75° 57′ for red (Li) light, 76° 12′ for yellow (Na) light, and 76° 22′ for green (Tl) light, and the optical sign negative. The optical sign is almost certainly incorrect, as stated above.

For the orientation of the optical ellipsoid, Flink gave the following angles:

$Bx_a : M$	51° 47′	$Bx_0 : M$	50° 7′*	$\beta : M$	63°*
$Bx_a : c$	51° 40′	$Bx_0 : c$	86° 55′*	$\beta : c$	38½°

These values are incompatible, and a little study shows that the supplementary value should be substituted for those marked with an asterisk, when the position, projected on b as above, becomes:

	Bx_a.	β.	Bx_0.
ϕ ...	343°	251°	74°
ρ ...	89°	39°	52°

No other investigator appears to have attempted the complete location of the optical ellipsoid, but a number of partial data are available, most of which support the present results.

A. Des Cloizeaux (loc. cit.) studied a rhodonite from Pajsberg, of optic axial angle (2V) 75° 4′, positive, and found the obtuse bisectrix nearly perpendicular to a (100), the axial plane being inclined about 10° to 12° to the normal in a direction towards m (110), and cutting the edge $[a:M]$ at about 39°, and $[a:k]$ at $5\frac{1}{2}$°, agreeing within 1° with the present results for the Harstig material which has the same sign and about the same axial angle. There was appreciable crossed dispersion about a. He also studied a bustamite from Långban, and found the acute bisectrix nearly perpendicular to a (100), the axial plane cutting the edge $[a:M]$ at 31°; the axial angle was 68° for red light and 72° for green, and the sign negative. There was strong crossed dispersion of the acute bisectrix. This, again, agrees well with the results for the present Långban material of somewhat higher axial angle. As will be seen below, this material was probably richer in lime than that analysed by Lindström (analysis IX).

Artificial manganese silicate, pure $MnSiO_3$, has been prepared and studied by C. S. Kallenberg [1] and L. Bourgeois.[2] The former found an extinction-angle of 31° on a (100), agreeing closely with the present value for a rhodonite containing 8 % of lime (analysis III); and the latter's extinction-angle of 18° on M ($1\bar{1}0$) also agrees well, but his statement that the axial plane is nearly perpendicular to M ($1\bar{1}0$) is probably an error.

E. S. Larsen and E. V. Shannon (loc. cit.) gave fragmentary data for bustamite with 25 % lime, from Franklin Furnace (complete analysis X below), comparable with the present specimen I in composition. They found α nearly perpendicular to a (100), β nearly perpendicular to b (010), and γ inclined 36° to the zone of cleavage [001], a clearly incompatible set of results. There was strong crossed dispersion of the negative acute bisectrix.

Thus the scanty data available on the optical orientation of rhodonites and bustamites support the present results, as far as they go. Unfortunately, there is no additional evidence to check the peculiar migration curve (fig. 1), but the marked dispersion of the bisectrices found in the Franklin Furnace material (I) is amply confirmed. This dispersion, which approximates to a crossed dispersion about a, is slight in the manganese-rich rhodonites, and increases with the calcium content, becoming very strong in the calcium-rich bustamites.

[1] C. S. Kallenberg, Centr. Min., 1914, p. 388.

[2] L. Bourgeois, Bull. Soc. Min. France, 1883, vol. 6, p. 64.

Turning to the refractive index and density data, these are by no means as numerous as could be desired, but are nevertheless sufficient to enable us to establish a straight line relation between these constants and the calcium or manganese ratio. For comparative purposes it is convenient to recalculate the analyses in molecular proportions, so that the sum of the monoxides (CaO, MgO, MnO, ZnO, FeO) is 100. Here we are only considering those members in which the total proportion of 'impurities' (MgO, ZnO, FeO) is low, not over about 10 % expressed as above, for the aim is to trace the effect of the replacement of manganese by calcium. Besides the results given above in the experimental part, the following data are available:

	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2 ...	93·54	96·18	100·8	89·92	100·75	98·29	95·01
MnO ...	87·14	73·42	80·34	69·46	59·05	55·28	43·27
FeO ...	2·65	5·75	0·62	1·66	1·65	0·83	0·46
ZnO ...	—	—	—	4·83	—	—	0·79
BaO ...	—	—	—	—	—	0·15	—
CaO ...	10·21	18·03	18·09	21·78	31·72	40·12	53·50
MgO ...	—	2·80	0·95	2·27	7·58	3·62	1·98
Sp. gr. ...	3·65	3·63	3·416	—	3·387	3·40	—
α ...	—	—	1·721	1·716	—	—	1·662
β ...	—	—	—	1·720	—	—	1·674
γ ...	—	—	1·730	1·732	—	—	1·676
2V ...	—	—	—	Med. large	—	—	44°±3°
Sign ...	—	—	—	Positive	—	—	Negative

IV. Viu, Turin, Italy. V. Fino, Atti Accad. Torino, 1883, vol. 18, p. 39.

V. Pajsberg, Sweden. L. J. Igelström, Öfv. Akad. Stockholm, 1851, p. 143; Journ. Prakt. Chem., 1851, vol. 54, p. 190.

VI. Val d'Err, Grisons, Switzerland. J. Jakob, Schweiz. Min. Petr. Mitt., 1923, vol. 3, p. 236.

VII. Franklin Furnace, New Jersey, U.S.A. E. S. Larsen and E. V. Shannon, Amer. Min., 1922, vol. 7, p. 149.

VIII. Radauthal, Harz, Germany. J. Fromme, Tschermak's Min. Petr. Mitt., 1909, vol. 25, p. 308.

IX. Långban, Sweden. G. Lindström, Öfv. Akad. Stockholm, 1880, vol. 37, no. 6, p. 57.

X. Franklin Furnace, New Jersey, U.S.A. E. S. Larsen and E. V. Shannon, Amer. Min., 1922, vol. 7, p. 95.

Pure manganese silicate ($MnSiO_3$) has been studied by several workers. C. S. Kallenberg (loc. cit.) found n 1·714 and sp. gr. 3·63; while A. Gorgeu[1] found sp. gr. 3·68; and A. S. Ginsberg[2] found n 1·74. The former pair of values give $(n-1)/d = 0{\cdot}197$, the latter, 0·201. C. S. Kallenberg also studied artificial preparations of

[1] A. Gorgeu, Bull. Soc. Min. France, 1887, vol. 10, p. 264.

[2] A. S. Ginsberg, Zeits. Anorg. Chem., 1908, vol. 59, p. 346.

various Ca/Mn ratios, but it is very doubtful how far his preparations were homogeneous, which would affect his refractive index determinations to some extent. He found:

CaO/(Ca,Mn)O ...	0	30	40	50	60	70	80
n	1·714	1·698	1·687	1·678	1·666	1·658	1·648

E. S. Larsen and E. V. Shannon examined several bustamites from Franklin Furnace, but unfortunately no one was completely studied.

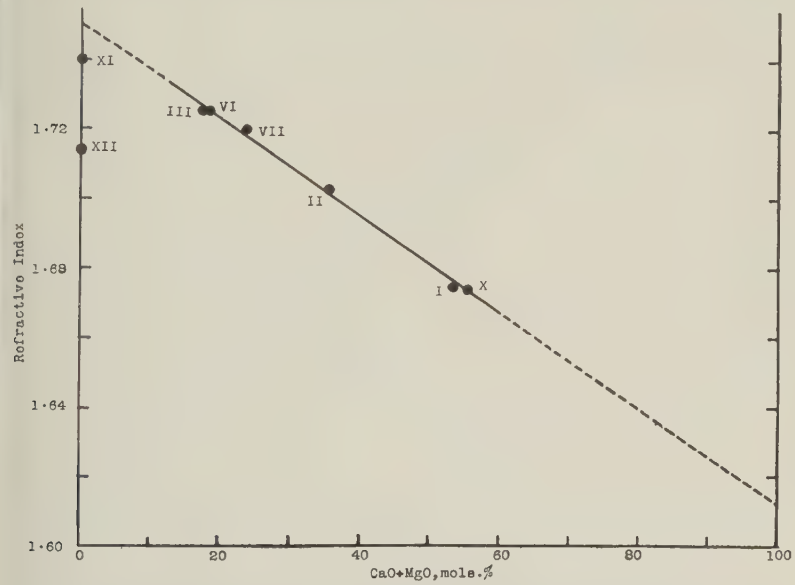


FIG. 2. Plot of the refractive index (β) against chemical composition in the rhodonite-bustamite series. (XI and XII, for artificial $MnSiO_3$, A. S. Ginsberg, 1908, and C. S. Kallenberg, 1914.)

One is set out above (analysis X); a second was only studied optically —it was optically negative, 2V medium, α 1·667, β 1·678, γ 1·680. The third was a zoned material, the manganese-rich core of which gave results set out above (analysis VII), while the outer zone, which was not analysed, was found to have α 1·687, β 1·692, γ 1·709, 2V medium, positive, strong crossed dispersion. Another specimen of similar material gave for the inner zone α 1·708, β 1·716, γ 1·724, 2V large, positive.

These refractive index and specific gravity data are shown in figs. 2 and 3 respectively. It will be seen that they are represented quite

well by straight lines; the limit of probable error may be taken as about 0·003 for refractive indices; for specific gravities a limit is much more difficult to fix without knowledge of the method used. As mentioned above, some of C. S. Kallenberg's refractive indices are probably unreliable, and J. Jakob's low value for the specific gravity of rhodonite from Val d'Err (VI) is probably an error. In plotting

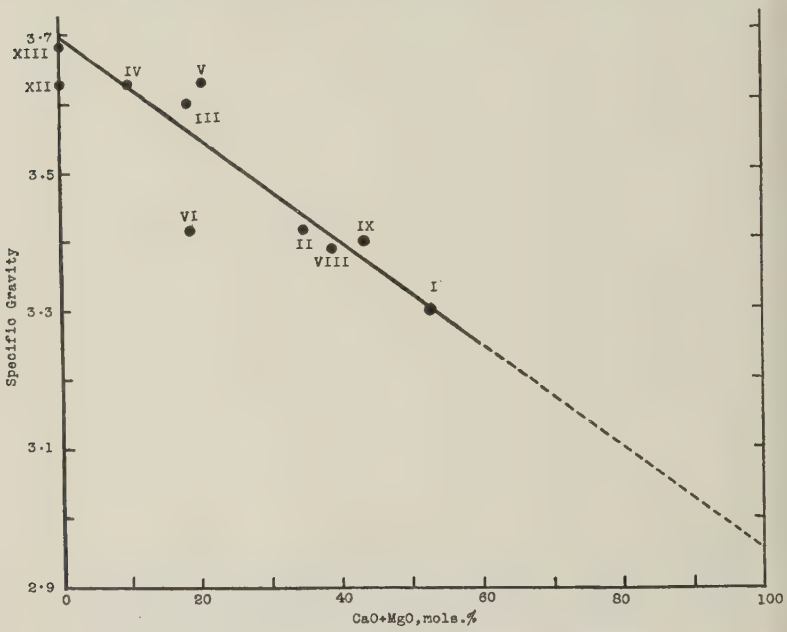


Fig. 3. Plot of the specific gravity against chemical composition in the rhodonite-bustamite series. (XII and XIII, for artificial $MnSiO_3$, C. S. Kallenberg, 1914, and A. Gorgeu, 1887.)

the specific gravities, the sum of the CaO and MgO has been taken as abscissae (the sum of the whole of the monoxides, in molecular parts, being taken as 100), for it seems preferable to include the magnesia with the lime rather than with the heavier oxides, MnO, FeO, and ZnO. If this is not done, analysis VIII falls right off the line, while the other points are not much affected, as they have but little magnesia.

The specific refractivities, $(\beta - 1)/d$, agree well with the values calculated, using E. S. Larsen's data[1] for CaO, MnO, and SiO_2, with

[1] E. S. Larsen, The microscopic determination of the nonopaque minerals. Bull. U.S. Geol. Survey, 1921, no. 679, p. 31.

the exception of the rhodonite from Val d'Err, for which Jakob's density is probably incorrect. The difference between $(\beta - 1)/d$ and

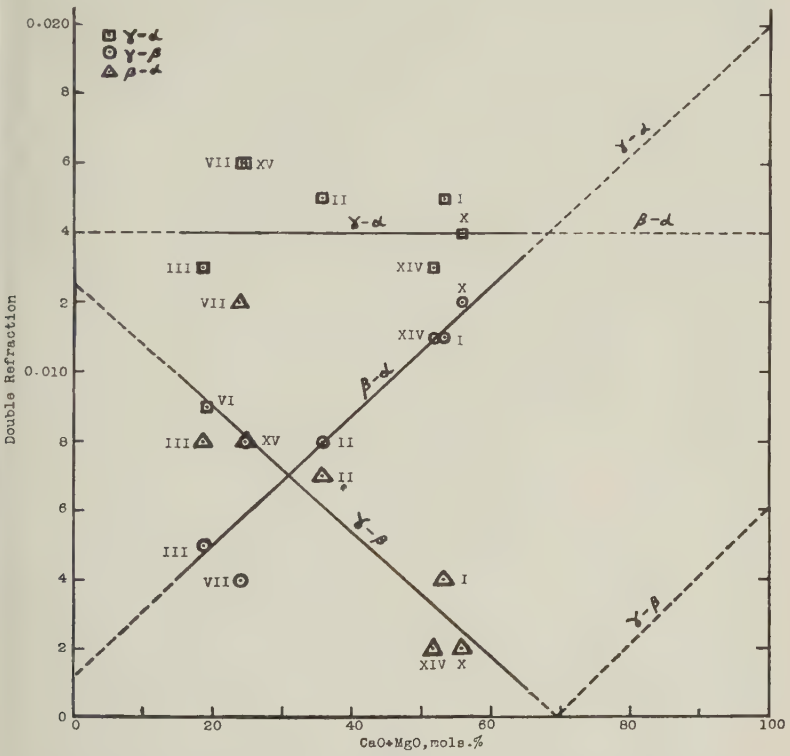


FIG. 4. Plot of the double refractions against chemical composition in the rhodonite-bustamite series. (XIV and XV, bustamite studied optically only by E. S. Larsen and E. V. Shannon, 1922. The chemical composition deduced from the refractive index (β) by the aid of fig. 2.)

$(\alpha + \beta + \gamma - 3)/3d$, the more correct form of the specific refractivity, is well within the limit of experimental error.

The discovery of the exact relations between the chemical composition and the optic axial angle and double refractions $\gamma - \alpha$ and $\beta - \alpha$ is not so easy. A priori, we should expect a straight line relationship for the double refractions, and if this is so, the optic axial angles cannot follow the same law. Unfortunately, the available data do not cover quite a large enough range to check this, but the assumption of a straight line law for the double refractions fits the

experimental results well within the limit of error. The data for the double refractions are quite erratic, for the probable error of the refractive index determinations is large in comparison with the double refractions. On the whole, $\gamma - \alpha$ appears to remain nearly constant at about 0·014, while $\beta - \alpha$ ranges from about 0·005 for the Harstig

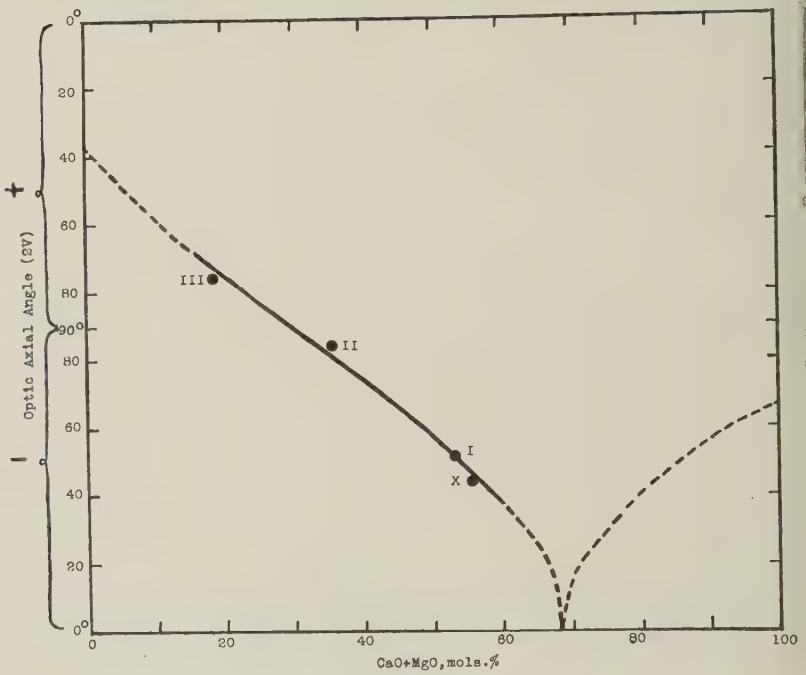


Fig. 5. Plot of the optic axial angle against chemical composition in the rhodonite-bustamite series.

rhodonite (III) to about 0·012 for Franklin Furnace bustamite (X). If we take $\gamma - \alpha$ as constant at 0·014, and plot $\beta - \alpha$ as a straight line function, using values calculated from $\gamma - \alpha$ and the measured values of 2V for the materials III and X (75° and 44°), and then take $\gamma - \beta$ by difference, we obtain the lines plotted in fig. 4, which will be seen to lie fairly well among their respective points. Then calculating 2V for other compositions from these lines for the double refractions, we obtain the curve shown in fig. 5, which agrees very well with the value experimentally found for the Långban bustamite (II) and gives the correct sign and rough magnitude for 2V in other instances, showing that our method is at least approximately right.

One interesting point emerges from these comparisons: the curves for $\gamma - \alpha$ and for $\beta - \alpha$ cross at about 70 mols. % of lime in the monoxides. Accordingly, bustamite of about this composition should exhibit crossed axial plane dispersion, becoming uniaxial for one wave-length, and the axes opening out in another plane with a further increase in the lime. This conclusion cannot be checked experimentally for lack of material, since the bustamite richest in lime (analysis X) had only 56 mols. % of lime and magnesia together.

We also see that the reasons raised by A. N. Winchell[1] for regarding artificial manganous silicate, rhodonite, and bustamite as separate species all disappear; the most important, viz. that the optic axial angles cannot be made into a continuous series, being based on an erroneous determination of the optical sign of rhodonite.

In a number of instances where an isomorphous series capable of all gradations covers a number of species, conventional limits have been set to the several species, defined, for example, by chemical composition, as in the albite-anorthite series. In the particular case of rhodonite and bustamite, a very convenient and natural division appears to be available in the optical sign, and it is suggested that all optically positive material should be called rhodonite, and all negative, bustamite. This will make bustamite cover all material containing 30 mols. % or more of lime in the monoxides, which corresponds roughly with the division at present made. In practice, the density or refractive index would of course be a more convenient criterion, and we see from graphs 3 and 2 that the division falls at a density of 3·47 or a refractive index (β) of 1·709.

In conclusion, I wish to acknowledge my indebtedness to Dr. L. J. Spencer for the introduction to a most interesting problem, and for his continual assistance and encouragement throughout the work, and to Mr. W. Campbell Smith, for instruction and assistance in the use of the Fedorov universal stage.

[1] A. N. Winchell, Amer. Min., 1927, vol. 12, p. 10 [Min. Abstr., 3–373].

Note added during proof correction:—

F. M. Jager and H. S. van Klooster, Proc. Sect. Sci. K. Akad. Wet. Amsterdam, vol. 18, pt. 2, p. 908, have studied artificial manganous silicate ($MnSiO_3$). The sp. gr. of 3·716 agrees well with the present results, but the optical data are not easily interpreted; the 107° rhombs with 14° extinction were probably tables parallel to b (010), giving α 1·733, and γ' 1·739 about midway between β and γ. Material prepared by Georgeu's method, and possibly less pure, was probably needles lying on a (100) and giving β 1·728 and γ 1·741. These optical constants agree fairly with the present results.

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